VOLUNTARY CARDIO-RESPIRATORY SYNCHRONIZATION: HARDWARE AND SOFTWARE DEVELOPMENT AND EVALUATION

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*Abstrac*t-Voluntary cardio-respiratory synchronization (VCRS) is a technique where an individual's breathing is voluntarily phase locked with his/her heart beat. A signal is generated (tone or light) from the ECG that is used to pace the breath with a fixed number of heart beats for inspiration and expiration. A small portable device was developed that can create a tone to pace the breathing and record the data for repeated measurements for extended periods of time (days or weeks). The device was tested on an individual over a four-week period. Measurements of heart rate variability were made at various times throughout the day for a total of 68 recordings. The data were analyzed to separate out respiratory and non-respiratory induced changes in the heart rate using a unique time domain analysis. The results showed significant variability over the measurement period.

Keywords **- heart rate variability, VCRS, breathing**

I. INTRODUCTION

It is well know that respiration is one of the strong contributors to heart rate variability. Under normal respiration, the breathing is not locked in time with the cardiac contraction. Therefore, the respiratory induced cardiac variations are non-stationary, and have a significantly different influence depending on when in the cardiac cycle respiration starts [1]. To improve stationarity, voluntary cardio-respiratory synchronization (VCRS) was developed [2]. The subject breathes in a normal manner but the breathing is synchronized with the heartbeat, using a signal in a predetermined ratio of the number of heartbeats for inspiration and expiration. An example of this is shown in Figure 1 for a 10 beat cycle. For the first four heart beats a tone comes on indicating to the subject to inspire. For the next six heart beats the tone is off indicating to the subject to expire.

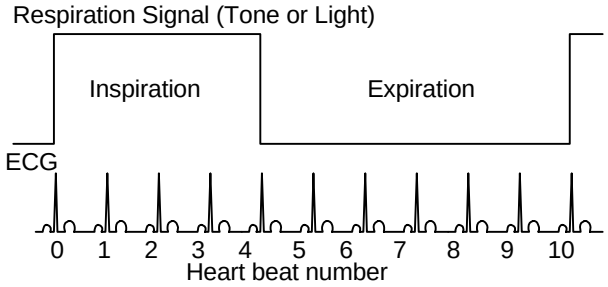

Fig. 1. Example of respiratory signal generated for a 10 heart beat cycle (four beats inspiration – six beats expiration).

This technique has been used to study heart rate variability as a function of age [2, 3], body position [3] and cardiotoxicity caused by chemotherapy [4]. Also, it has been used to reduce respiratory variations in cardiac impedance signals [5].

The purpose of the research was to develop and test a small portable device for the study of heart rate variability and R wave to pulse interval as a function of time over a period of many weeks.

II. METHODOLOGY

In order to record data repeatedly over many days a small portable device (11 x 6 x 2 cm) was designed, which is referred to as the SynchroMax. It was developed around a PIC microprocessor with memory (64K) capable of holding 32,000 beats. It can be programmed for various numbers of beats for inspiration and expiration. It was designed to measure the time interval between the R waves of the ECG (RR) and the R wave to a peripheral pulse (RP) detected with a photo-sensor. The RP interval represents the pre-ejection period plus the pulse wave velocity. The sampling rate of the time interval is 2000/s with the data rounded and saved to the nearest ms. The R pulse is detected from the electromagnetic pulse emitted by a Polar® chest belt.

In the study a subject was followed over a four week period with measurements made at various times over the day. A total of 68 measurements were made with RR intervals and 45 with RP intervals. Each measurement bout recorded 75 breathing cycles with 10 heart beats for each breath cycle. For the first four heartbeats the subject inspired and for the next six heartbeats he expired. This resulted in a breathing frequency of approximately 0.1 Hz, suggested to be a resonance frequency of the cardiovascular system [5].

Figure 2 shows a typical averaged RR interval response for 75 breath cycles. Figure 3 shows a similar graph for the RP interval. The average and standard deviation of each of the heartbeats in the respiratory cycle were calculated based on their position in the respiratory cycle as shown in fig. 1. Six parameters were calculated for each of the VCRS measurement periods (three applied for RR and three for RP). The average amplitude of the RR or RP variation over the respirations cycle (RRRA or RPRA), the standard deviation of the RR or RP interval measured around the mean for each beat of the respiratory cycle averaged over all beats (this is a measure of the non-respiratory induced variability, RRSD or RPSD), and the RR or RP Index = RRRA/RRSD or RPRA/RPSD.

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Abstract

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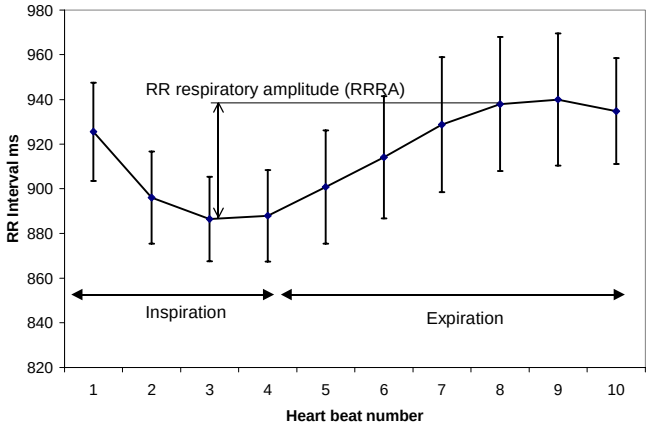

Fig. 2. Typical average RR response for 75 breath cycles

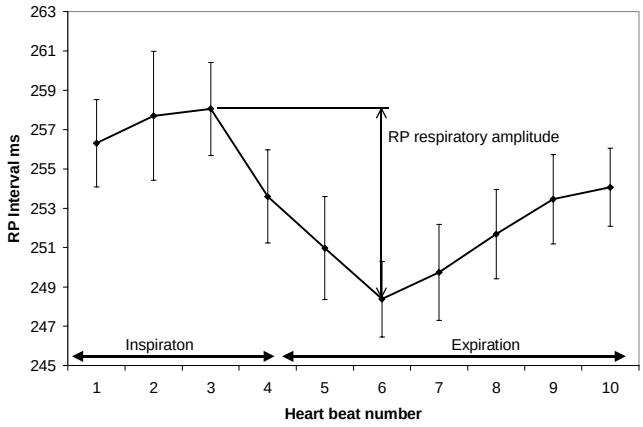

Fig. 3. Typical average RP response for 75 breath cycles

Using VCRS a calculation of the respiratory and non-respiratory heart rate variability can be performed using time domain methods. RRRA reflects the respiratory modulation of the RR interval whereas RRSD reflects the non-respiratory variability.

Figure 4 shows the raw RR interval data and the same data with the average variation for each beat in the respiratory cycle removed. For example, the average value of the RR interval for beat 1 would be subtracted for individual beats that occurred during the first beat in the respiratory cycle. The same computation is performed for each of the beats in the respiratory cycle. In order to place the new RR series on the same scale the overall average RR interval beat was added to each beat. A Fourier analysis was calculated for each of the series with and without respiration removed (upper two traces). Comparing the lower two traces in figure 4 shows the peak due to respiratory at about 0.1 Hz was completely removed.

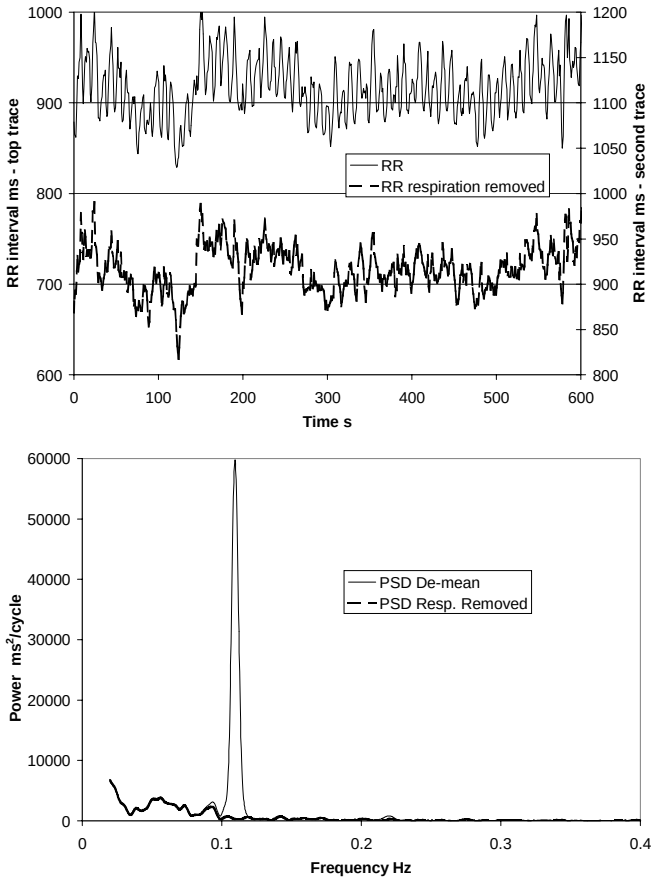

Fig. 4. Top trace raw RR interval used in fig. 2. Second trace RR interval data with respiration removed. Third and fourth traces show the frequency domain analysis of upper two traces. Resp = Respiration.

III. RESULTS

The average ±SD over all measurement periods was RRRA 60.3±38.8 ms, RRSD 42.1±18.8 ms, RRIndex 1.37±.44, RPRA 7.6 ±2.7 ms, RPSD 4.9±4.3 ms, and RPIndex 2.21±1.18. Figure 5 shows the RRRA and RRSD as a function of the time of day. Figure 6 shows the RRIndex during the same time period. Figure 7 shows the RRRA compared to the RRSD.

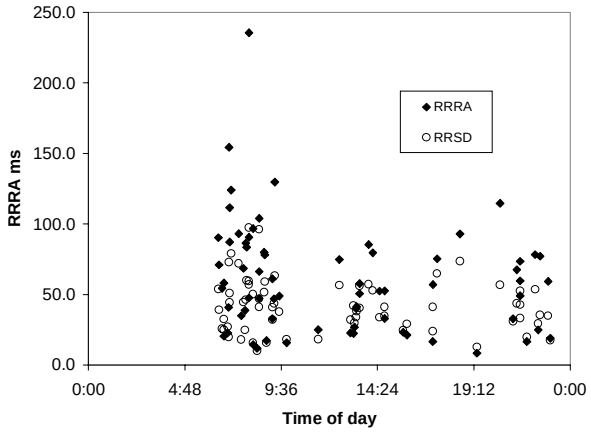

Fig. 5. RRRA and RRSD values as function of time of day

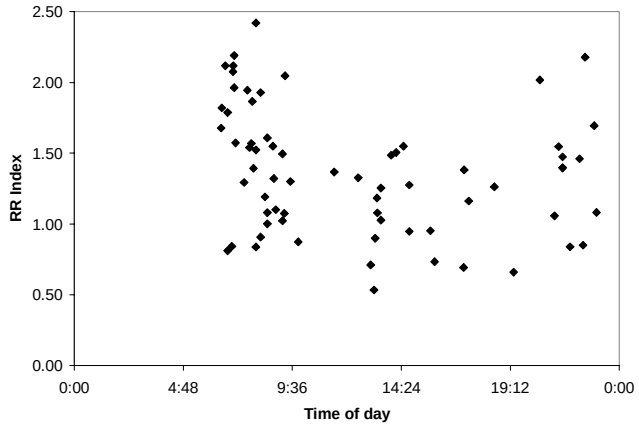

Fig. 6. RRIndex as a function of time of day

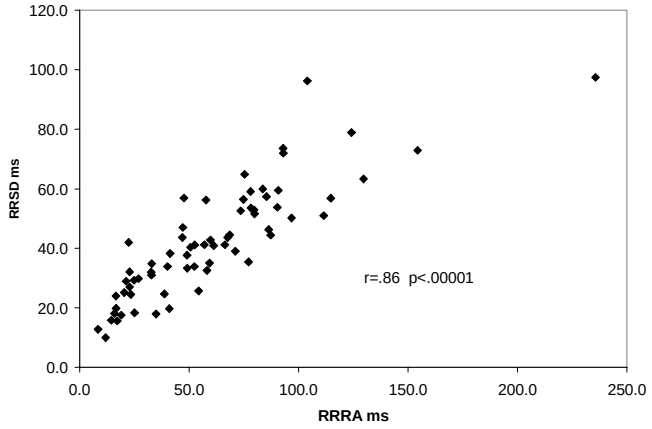

Fig. 7. RRRA vs. RRSD

IV. Discussion

The results show a striking variability in both the amplitude of respiratory induced change and the RR Index. Although it has been suggested that RR variability can indicate poor prognosis of various disease states, these data suggest that unless data is taken over many days and at various times throughout the day incorrect conclusions would be made due to the large variability.

The RRIndex is a ratio of the respiratory induced variability and non-respiratory variability. In frequency domain analysis the high frequency (HF) spectral power (0.15-0.4 Hz) is associated with the parasympathetic nervous system and lower frequency (LF) power is associated with sympathetic and parasympathetic system.

The SynchroMax is a small and easy to use device that can be incorporated into a larger study to collect data using VCRS methodology to analyze heart rate variability.

V. Conclusion

This study demonstrated that the SynchroMax device and associated software analysis methodology offers a feasible way to study heart rate variability in a new manner. The data also revealed the need for repeated measures during different times of the day to obtain an estimate of an individual's heart rate variability.

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